

Oil & Natural Gas Technology

DOE Award No.: DE-FC26-03NT15424

DELIVERABLE 1-4 FIELD MAPS AND CROSS SECTIONS: LISBON FIELD, SAN JUAN COUNTY, UTAH

THE MISSISSIPPIAN LEADVILLE LIMESTONE EXPLORATION PLAY, UTAH AND COLORADO – EXPLORATION TECHNIQUES AND STUDIES FOR INDEPENDENTS

Submitted by:
Utah Geological Survey
Salt Lake City, Utah 84114

Prepared for:
United States Department of Energy
National Energy Technology Laboratory

July 2007



Office of Fossil Energy

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**DELIVERABLE 1-4
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LISBON FIELD,
SAN JUAN COUNTY, UTAH**



by

*Craig D. Morgan,
Kevin McClure,
Thomas C. Chidsey, Jr., Principal Investigator/Program Manager,
Utah Geological Survey
David E. Eby, Eby Petrography and Consulting, Inc.,*

US/DOE Patent Clearance is not required prior to the publication of this document.

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INTRODUCTION

The Mississippian Leadville Limestone has produced over 53 million barrels (bbls) (8.4 million m³) of oil from six fields in the northern Paradox Basin region, referred to as the Paradox fold and fault belt, of Utah and Colorado. All of these fields are currently operated by independent producers. Only independent producers continue to explore for Leadville oil targets in the region, 85 percent of which is under the stewardship of the federal government. This 7500-square-mile (19,400 km²) area is relatively unexplored with only about 100 exploratory wells that penetrated the Leadville (less than one well per township), and thus the potential for new discoveries remains great.

The overall goals of this study are to (1) develop and demonstrate techniques and exploration methods never tried on the Leadville Limestone, (2) target areas for exploration, (3) increase deliverability from new and old Leadville fields through detailed reservoir characterization, (4) reduce exploration costs and risk especially in environmentally sensitive areas, and (5) add new oil discoveries and reserves. These goals are designed to assist the independent producers and explorers who have limited financial and personnel resources.

Exploring for hydrocarbons in the Leadville Limestone is high risk, with less than a 10 percent chance of success based on the drilling history of the region. Prospect definition requires expensive, three-dimensional (3D) seismic acquisition, often in environmentally sensitive areas. These facts make exploring difficult for independents that have limited funds available to try new, unproven techniques that might increase the chance of successfully discovering oil. We believe that one or more of the project activities will reduce the risk taken by an independent producer in looking for Leadville oil, not only in exploring but also in trying new techniques.

Another problem in exploring for oil in the Leadville Limestone is the lack of published or publicly available geologic and reservoir information, such as regional facies maps, complete reservoir characterization studies, surface geochemical surveys, regional hydrodynamic pressure regime maps, and oil show data and migration interpretations. This project provides this information to save independents cash and staffing resources which they simply do not possess or normally have available only for drilling. The technology, maps, and studies generated from this project will help independents to identify or eliminate areas and exploration targets prior to spending significant financial resources on seismic data acquisition and environmental litigation, and therefore increase the chance of successfully finding new accumulations of Leadville oil.

GEOLOGIC SETTING

Paradox Basin Overview

The Paradox Basin is located mainly in southeastern Utah and southwestern Colorado, with a small part in northeastern Arizona and northwestern New Mexico (figure 1). The Paradox Basin is an elongate, northwest-southeast-trending, evaporitic basin that predominantly developed during the Pennsylvanian. The basin can generally be divided into three areas: the Paradox fold and fault belt in the north, the Blanding sub-basin in the south-southwest, and the Aneth platform in southeasternmost Utah (figure 1). The Mississippian Leadville Limestone is one of two major oil and gas reservoirs in the Paradox Basin, the other being the Pennsylvanian Paradox Formation (figure 2). Most Leadville production is from the Paradox fold and fault belt (figure 3).

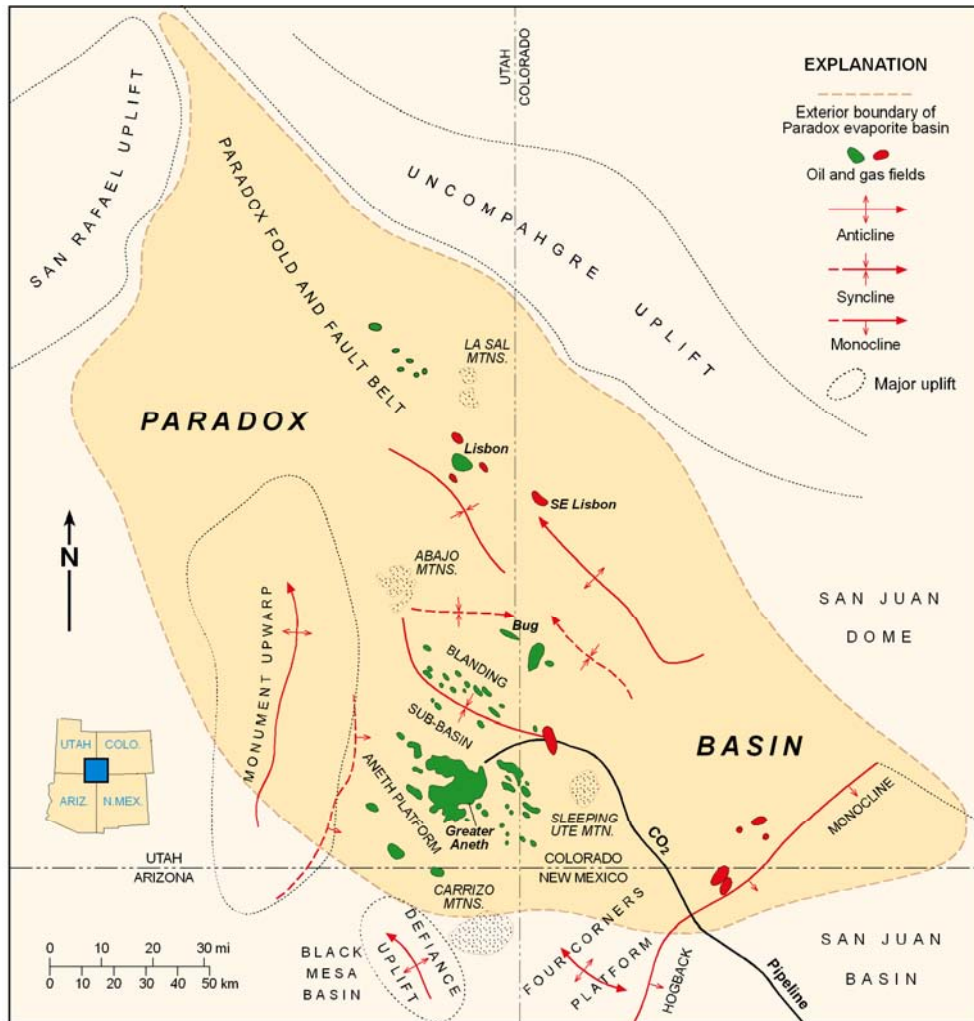


Figure 1. Oil and gas fields in the Paradox Basin of Utah and Colorado.

PENN	Hermosa Group	Paradox Fm	2000-5000'		potash & salt
		Pinkerton Trail Fm	0-150'		
	Molas Formation		0-100'		
M	Leadville Limestone		300-600'		
DEV	Ouray Limestone		0-150'		
	Elbert Formation		100-200'		
C	McCracken Ss M		25-100'		
	"Lynch" Dolomite		800-1000'		

Oil and gas production

Figure 2. Stratigraphic column of a portion of the Paleozoic section determined from subsurface well data in the Paradox fold and fault belt, Grand and San Juan Counties, Utah (modified from Hintze, 1993).

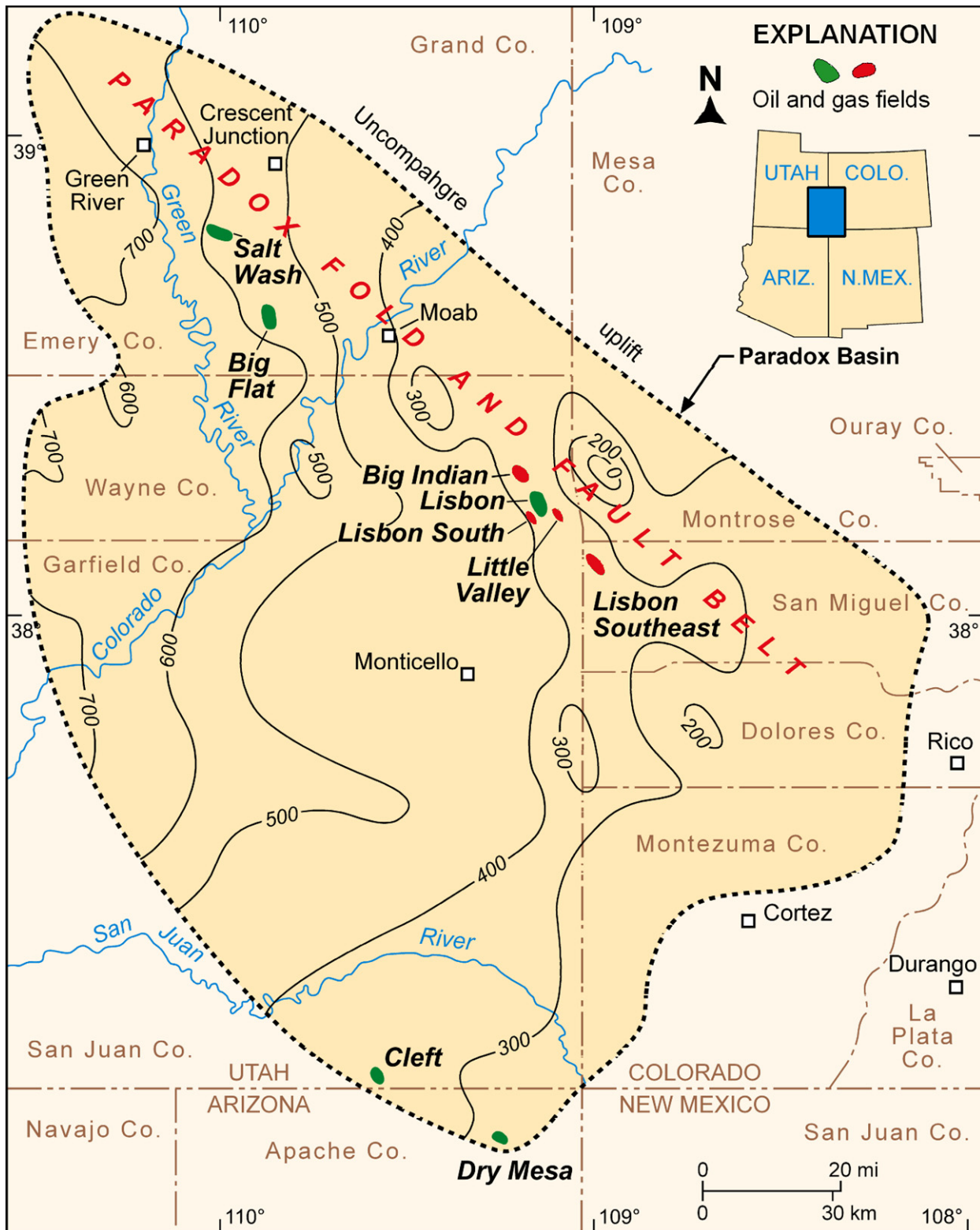


Figure 3. Location of fields that produce from the Mississippian Leadville Limestone, Utah and Colorado. Thickness of the Leadville is shown; contour interval is 100 feet (modified from Parker and Roberts, 1963).

The most obvious structural features in the basin are the spectacular anticlines that extend for miles in the northwesterly trending fold and fault belt. The events that caused these and many other structural features to form began in the Proterozoic, when movement initiated on high-angle basement faults between 1700 and 1600 Ma (Stevenson and Baars, 1987). During Cambrian through Mississippian time, this region, as well as most of eastern Utah, was the site of typical thin, marine deposition on the craton while thick deposits accumulated in the miogeocline to the west (Hintze, 1993). However, major changes occurred beginning in the Pennsylvanian. A series of basins and fault-bounded uplifts developed from Utah to Oklahoma as a result of the collision of South America, Africa, and southeastern North America (Kluth and Coney, 1981; Kluth, 1986), or from a smaller-scale collision of a microcontinent with south-central North America (Harry and Mickus, 1998). One result of this tectonic event was the uplift of the Ancestral Rockies in the western United States. The Uncompahgre Highlands in eastern Utah and western Colorado initially formed as the westernmost range of the Ancestral Rockies during this ancient mountain-building period. The southwestern flank of the Uncompahgre Highlands (uplift) is bounded by a large, basement-involved, high-angle reverse fault identified from seismic surveys and exploration drilling. As the highlands rose, an accompanying depression, or foreland basin, formed to the southwest – the Paradox Basin. Rapid subsidence, particularly during the Pennsylvanian and continuing into the Permian, accommodated large volumes of evaporitic and marine sediments that intertongue with non-marine arkosic material shed from the highland area to the northeast (Hintze, 1993).

The Paradox Basin is surrounded by other uplifts and basins that formed during the Late Cretaceous-early Tertiary Laramide orogeny (figure 1). The Paradox fold and fault belt was created during the Tertiary and Quaternary by a combination of (1) reactivation of basement normal faults, (2) salt flowage, dissolution and collapse, and (3) regional uplift (Doelling, 2000).

Most oil and gas produced from the Leadville Limestone is found in basement-involved, northwest-trending structural traps with closure on both anticlines and faults (figure 4). Lisbon, Big Indian, Little Valley, and Lisbon Southeast fields (figure 3) are sharply folded anticlines that close against the Lisbon fault zone. Salt Wash and Big Flat fields (figure 3), northwest of the Lisbon area, are east-west- and north-south-trending anticlines, respectively.

Regional Leadville Facies

The Mississippian (late Kinderhookian through Osagean to early Meramecian time) Leadville Limestone is a shallow, open-marine, carbonate-shelf deposit (figure 5). The western part of the Paradox fold and fault belt includes a regional, reflux-dolomitized, interior bank facies containing Waulsortian mounds (Welsh and Bissell, 1979). During Late Mississippian time, the entire carbonate platform in southeastern Utah and southwestern Colorado was subjected to subaerial erosion resulting in formation of a lateritic regolith (Welsh and Bissell, 1979). This regolith and associated carbonate dissolution is an important factor in Leadville reservoir potential (figure 6). Solution breccia and karstified surfaces are common, including possible local development of cavernous zones (Fouret, 1982, 1996).

The Leadville Limestone thins from more than 700 feet (230 m) in the northwest corner of the Paradox Basin to less than 200 feet (70 m) in the southeast corner (Morgan, 1993) (figure 3). Thinning is a result of both depositional onlap onto the Mississippian cratonic shelf and erosion. The Leadville is overlain by the Pennsylvanian Molas Formation and underlain by the Devonian Ouray Limestone (figure 2).

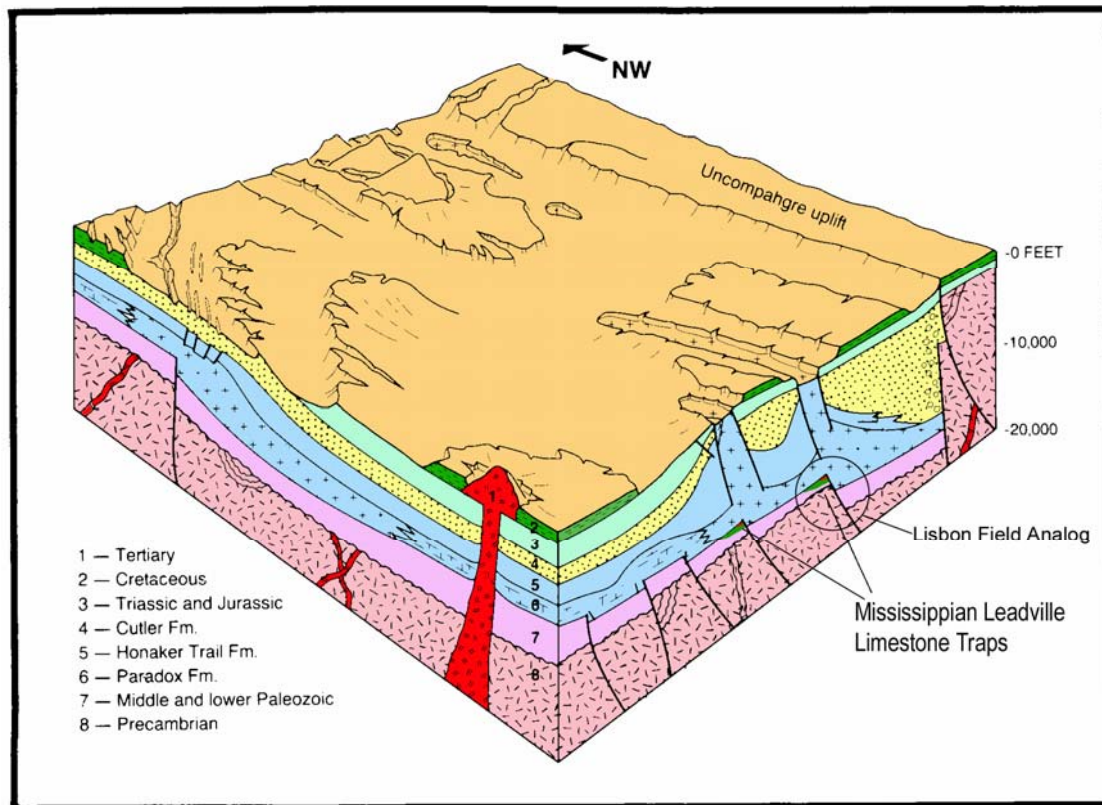


Figure 4. Schematic block diagram of the Paradox Basin displaying basement-involved structural trapping mechanisms for the Leadville Limestone fields (modified from Petroleum Information, 1984; original drawing by J.A. Fallin).

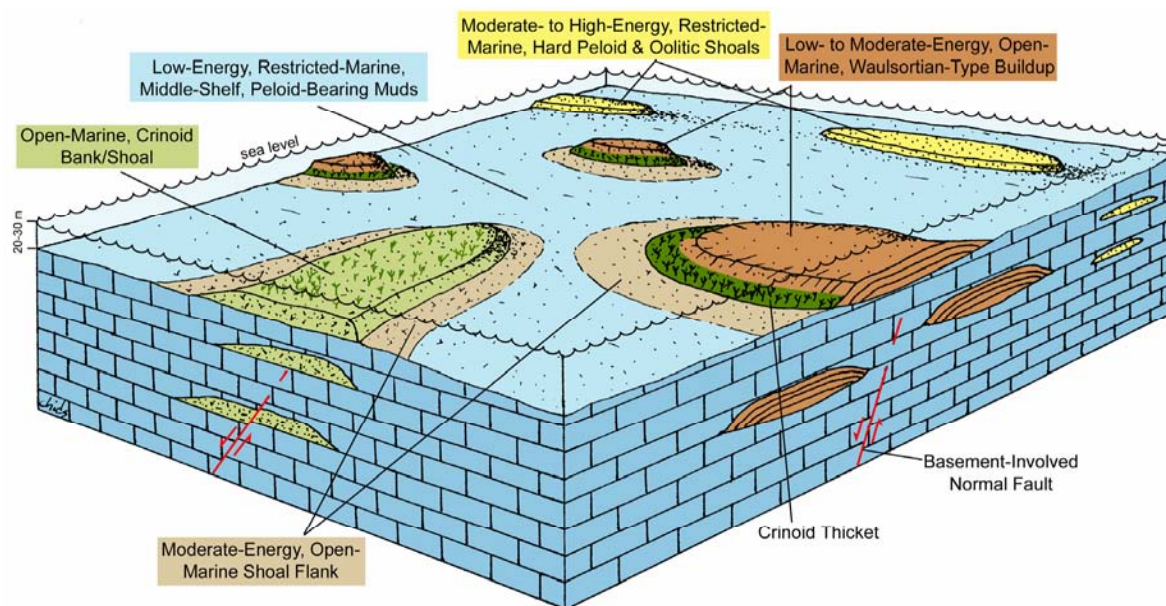


Figure 5. Block diagram displaying major depositional facies, as determined from core, for the Leadville Limestone, Lisbon field, San Juan County, Utah.

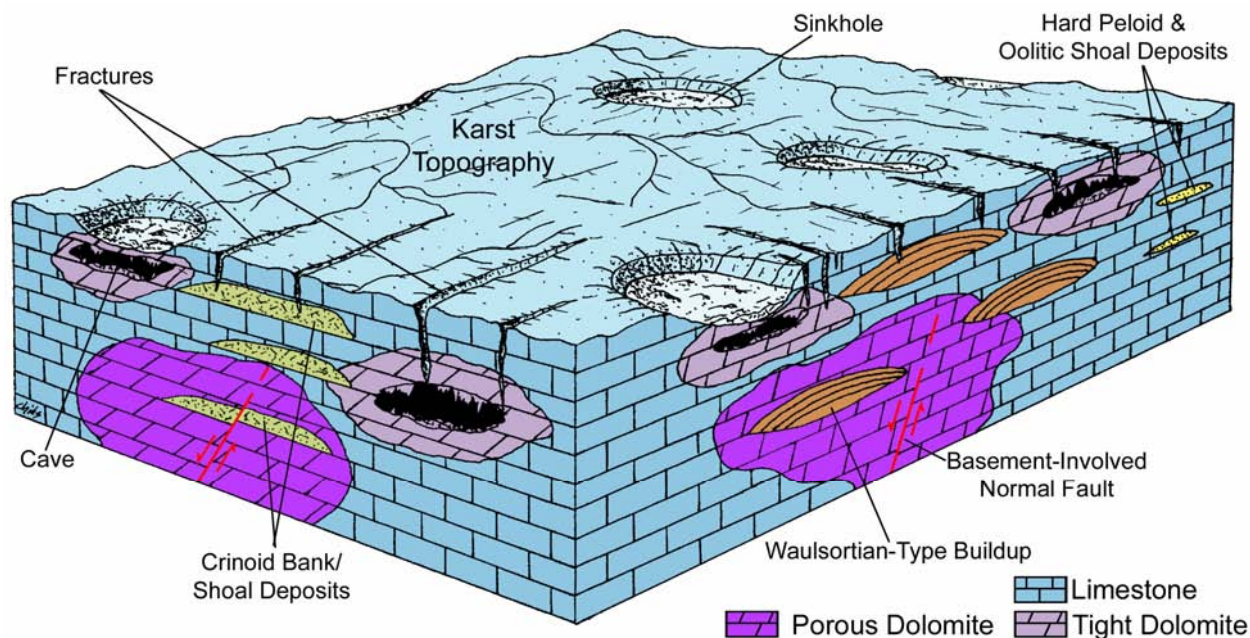


Figure 6. Block diagram displaying post-Leadville karst and fracture overprint.

Periodic movement along northwest-trending faults affected deposition of the Leadville Limestone. Crinoid banks or mounds, the primary reservoir facies (figure 5), accumulated in shallow-water environments on upthrown fault blocks or other paleotopographic highs. In areas of greatest paleorelief, the Leadville is completely missing as a result of non-deposition or subsequent erosion (Baars, 1966).

The Leadville Limestone is divided into two members separated by an intraformational disconformity. The dolomitic lower member is composed of mudstone, wackestone, packstone, and grainstone deposited in shallow-marine, subtidal, supratidal, and intertidal environments (Fouret, 1982, 1996). Fossils include crinoids, fenestrate bryozoans, and brachiopods. Locally, mud-supported boundstone creates buildups or mud mounds (Waulsortian facies), involving growth of “algae” (Wilson, 1975; Fouret, 1982, 1996; Ahr, 1989). The upper member is composed of mudstone, packstone, grainstones (limestone and dolomite), and terrigenous clastics also deposited in subtidal, supratidal, and intertidal environments (Fouret, 1982, 1996). Fossils include crinoids and rugose coral. Reservoir rocks are crinoid-bearing packstone (Baars, 1966).

LISBON CASE-STUDY FIELD, SAN JUAN COUNTY, UTAH

Introduction and Field Synopsis

Lisbon field, San Juan County, Utah (figure 3) accounts for most of the Leadville oil production in the Paradox Basin. A wealth of Lisbon core, petrographic, and other data is available to the UGS. The reservoir characteristics, particularly diagenetic overprinting and history, and Leadville facies can be applied regionally to other fields and exploration trends in the Paradox Basin. Therefore, we selected Lisbon as the major case-study field for the

Leadville Limestone project. This evaluation included data collection, and construction of various maps (top of structure, thickness, porosity, and so forth) and cross sections as summarized in this report.

The Lisbon trap is an elongate, asymmetric, northwest-trending anticline, with nearly 2000 feet (600 m) of structural closure and bounded on the northeast flank by a major, basement-involved normal fault with over 2500 feet (760 m) of displacement (Smith and Prather, 1981) (figure 7). Several minor, northeast-trending normal faults divide the Lisbon Leadville reservoir into compartments.

Producing units in Lisbon field contain dolomitized crinoidal/skeletal grainstone, packstone, and wackestone fabrics. Diagenesis includes fracturing, autobrecciation, karst development, hydrothermal dolomite, and bitumen plugging. The net reservoir thickness is 225 feet (69 m) over a 5120-acre (2100 ha) area (Clark, 1978; Smouse, 1993). Reservoir quality is greatly improved by natural fracture systems associated with the Paradox fold and fault belt. Porosity averages 6 percent in intercrystalline and moldic networks enhanced by fractures; permeability averages 22 millidarcies (mD). The drive mechanism is an expanding gas cap and gravity drainage; original water saturation was 39 percent (Clark, 1978; Smouse, 1993). The bottom-hole temperature ranges from 133 to 189°F (56-87°C).

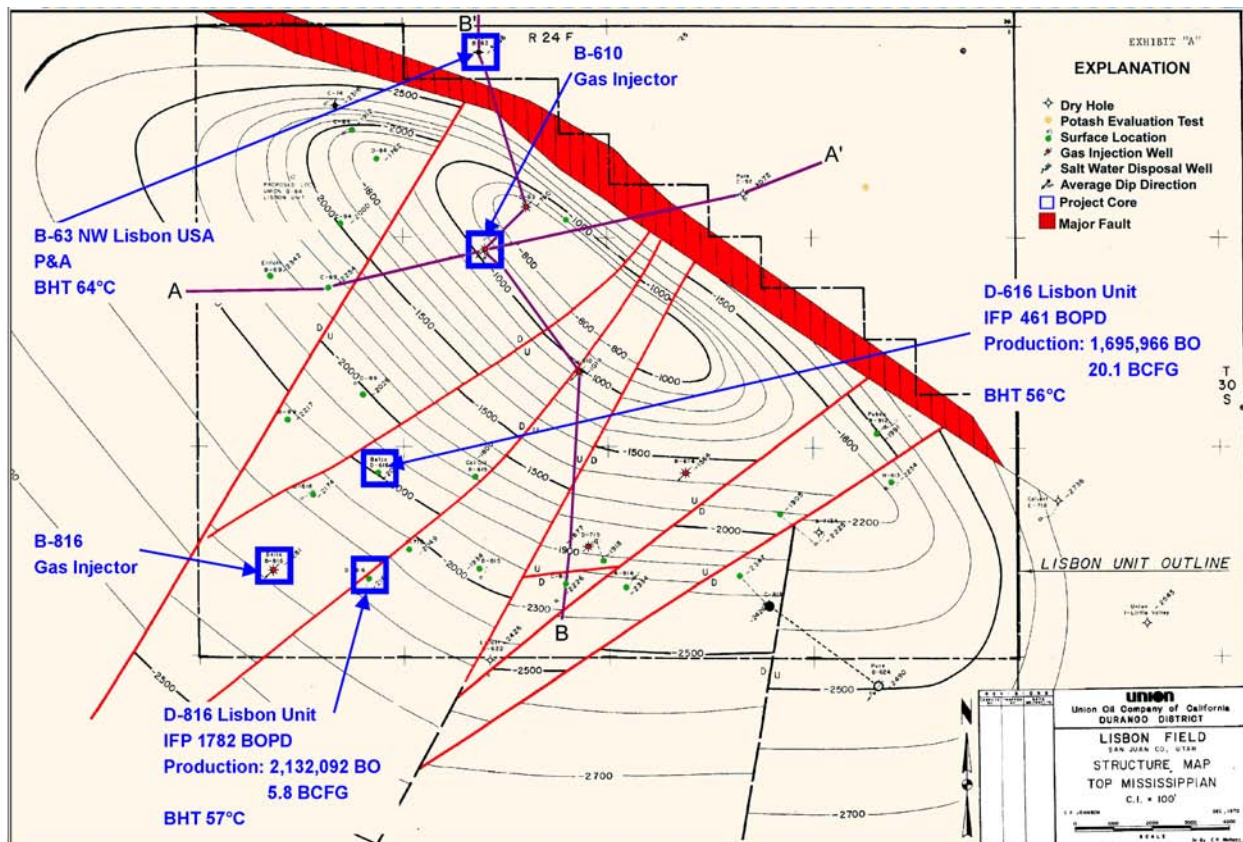


Figure 7. Top of structure of the Leadville Limestone, Lisbon field, San Juan County, Utah (modified from C.F. Johnson, Union Oil Company of California files, 1970; courtesy of Tom Brown, Inc.). Also displayed are wells from which cores were described in this study.

Lisbon field was discovered in 1960 with the completion of the Pure Oil Company No. 1 NW Lisbon USA well, NE1/4NW1/4 section 10, T. 30 S., R. 24 E., SLBL&M (figure 7), with an initial flowing potential (IFP) of 179 bbls of oil per day (BOPD) (28 m³) and 4376 thousand cubic feet of gas per day (124 MCMPD). The original reservoir field pressure was 2982 pounds per square inch (psi [20,560 kPa]) (Clark, 1978). Currently, 20 producing (or shut-in) wells, 11 abandoned producers, five injection wells (four gas injection wells and one water/gas injection well), and four dry holes are in the field. Cumulative production as of March 1, 2007, was 51,154,824 bbls of oil (8,133,617 m³), 790.9 billion cubic feet of gas (BCFG) (22.4 BCMG) (cycled gas), and 50,262,600 bbls of water (7,991,753 m³) (Utah Division of Oil, Gas and Mining, 2007). Hydrocarbon gas that was re-injected into the crest of the structure to control pressure decline is now being produced; acid gas is still re-injected.

Three factors create reservoir heterogeneity within productive zones: (1) variations in carbonate fabrics and facies, (2) diagenesis (including karstification), and (3) fracturing. The extent of these factors and how they are combined affect the degree to which they create barriers to fluid flow.

Data Collection and Compilation

Geophysical well logs, cores and cuttings, reservoir data, various reservoir maps, and other information from Lisbon field development wells were collected by the UGS. Well locations, formation tops, production data, completion tests, basic core analysis, porosity and permeability data, and other data were compiled and entered in a database developed by the UGS. This database, INTEGRAL, is a geologic-information database that links a diverse set of geologic data to records using MS AccessTM. The database is designed so that geological information, such as lithology, petrophysical analyses, or depositional environment, can be exported to software programs to produce cross sections, strip logs, lithofacies maps, various graphs, and other types of presentations. The database containing information on the geological reservoir characterization case study as well as later regional correlations will be available at the UGS's Leadville Limestone project Web site page, <http://geology.utah.gov/emp/leadville/index.htm>, at the conclusion of the project.

LOG-BASED CORRELATION SCHEME

The typical vertical sequence or cycle of depositional facies from Lisbon field, as determined from conventional core, was tied to the corresponding gamma-ray and neutron-density curves from geophysical well logs (figure 8). The correlation scheme enabled us to identify the major zone contacts, seals or barriers, baffles, producing or potential reservoirs, and depositional facies. These contacts were used to produce field cross sections (figure 9 and plates 1 and 2) and a variety of structure and isochore maps (figures 7, and A-1 through A-8 in the appendix).

Seals or barriers include thick shales of the Molas Formation, which overlies the Leadville Limestone. Baffles are those rock units that restrict fluid flow in some parts of the field but may develop enough porosity and permeability in other parts, through diagenetic processes or facies changes, to provide a conduit for fluid flow or even oil storage. Baffles are found throughout the Leadville stratigraphic section. The four reservoir zones defined in this study (1 through 4, from top to bottom) are those units containing 8 percent or more porosity based on the average of the neutron and density porosity values (see plates 1 and 2).

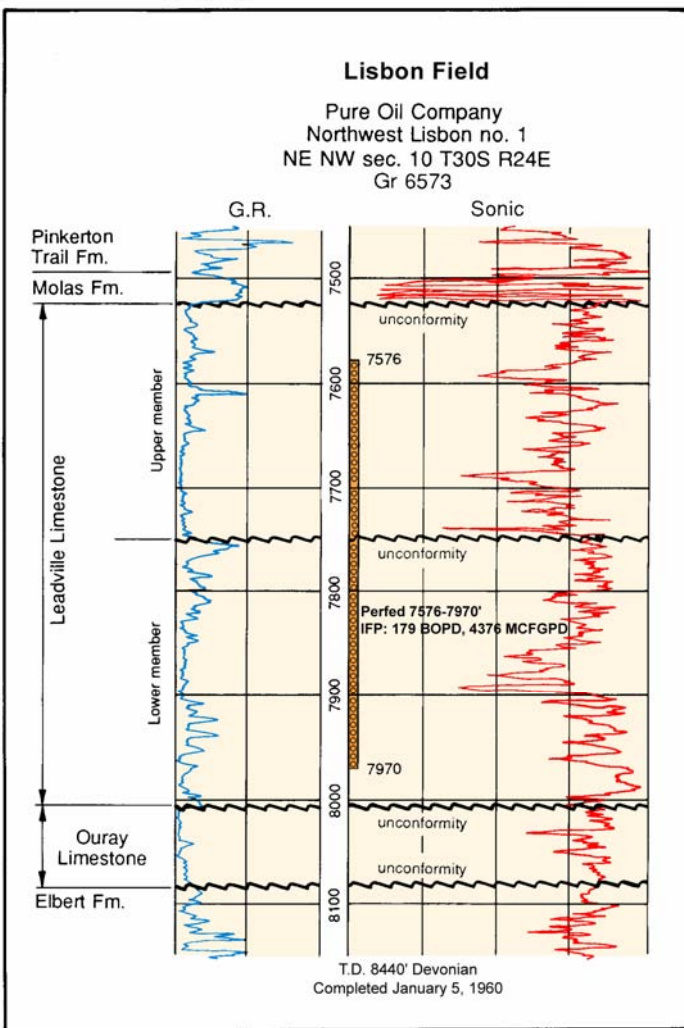


Figure 8. Typical gamma ray-sonic log of the Leadville Limestone, Lisbon field discovery well, San Juan County, Utah. See figure 7 for location of Lisbon field wells.

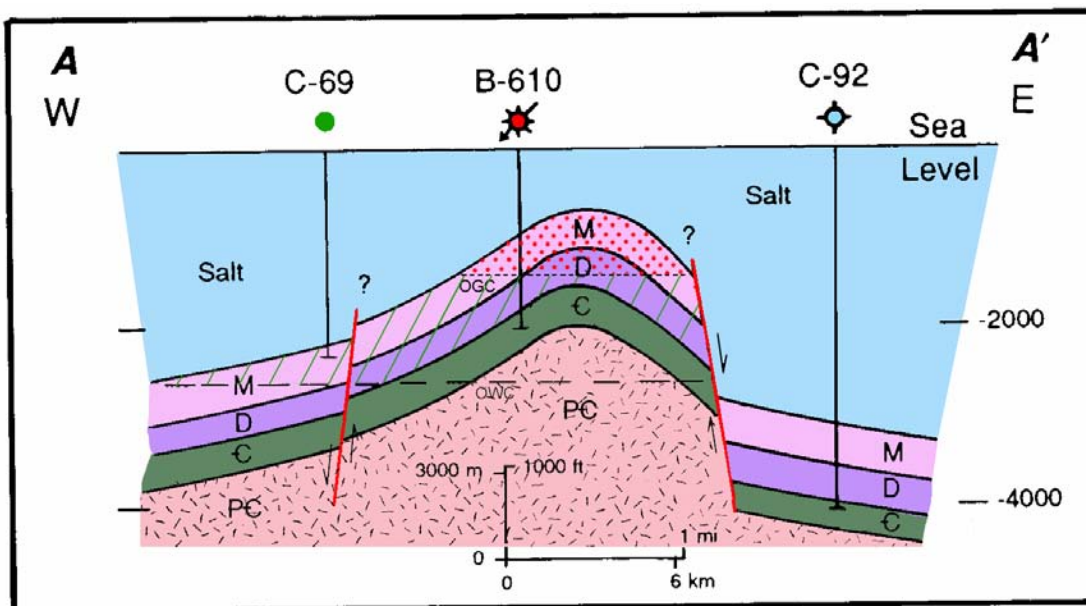


Figure 9. Schematic east-west structural cross section, Lisbon field. Modified from Clark, 1978.

Depositionally, rock units are divided into crinoid banks/shoals, Waulsortian-type carbonate buildups (mounds) (bafflestone, bindstone, grainstone, and packstone), and inter-bank/shoal and inter-mound seals or barriers (mudstone and shale). Associated with Waulsortian carbonate-buildup rock units are flank/off buildups (floatstone, rudstone, wackestone, and mudstone). Porosity units, and reservoir or potential reservoir layers, are identified within the crinoid banks/shoals and carbonate-buildup and flank/off-buildup intervals. The crinoid banks/shoals and carbonate-buildup units, and some of the flank/off-buildup units contain all productive reservoir facies.

The correlation scheme was used for (1) predicting changes in reservoir and non-reservoir rocks across the field, (2) comparing field to non-field areas, (3) estimating the reservoir properties and identifying facies in wells which were not cored, and (4) determining potential units suitable for horizontal drilling projects. It can be applied to other fields in the Paradox Basin, both those with cores and without.

RESERVOIR MAPPING

We constructed isochore maps of reservoir zones 1 through 4 in the Leadville Limestone for Lisbon field (figures A-1 through A-4). These field maps incorporate zone tops and thickness from all geophysical well logs in the area. We generated the net feet of porosity isochore maps for reservoir zones 1 through 4 (figures A5 through A8) of the Leadville for those parts of the reservoir units containing 10 percent or more porosity based on the average of the neutron and density porosity values. While 8 percent or more porosity defines the reservoir zones, we used 10 percent or more porosity for greater definition of the zones mapped. The maps display well names, Leadville completions, and interval thickness for each well.

We plotted the bottom-hole temperature for most wells in Lisbon field (figure A-9). The maps also include faulting. Contoured temperatures identify possible patterns in temperature data. All wells with available core show evidence of hydrothermal dolomitization. The presence of hydrothermal dolomite and its relationship to reservoir temperature and faulting are critical in identifying diagenetic trends.

We conducted production analysis for Lisbon field by compiling data through two principal tasks: (1) review of existing well-completion data, and (2) determination of production history from monthly production reports available through the Utah Division of Oil, Gas and Mining. We merged this information with geological characterization data and incorporated into the interpretation of reservoir diagenesis (Chidsey and others, 2005a, 2005b, 2005c; Eby and others, 2005).

Well-test data can provide key insights into the nature of reservoir heterogeneities, and also provide "large-scale" quantitative data on actual reservoir properties and facies from the Lisbon case-study reservoir. Although a number of well tests have been conducted in all of the target reservoirs, only the IFP well tests provide quantitative reservoir property information. We plotted IFP well tests for each well (figure A-10). Oil production from Lisbon field has shown a steady decline since peaking in the 1970s. We plotted cumulative production for each well (figure A-11). These plots are used to determine possible production "sweet spots" and their relationship to faulting and reservoir diagenesis.

ACKNOWLEDGMENTS

Funding for this research was provided as part of the Advanced and Key Oilfield Technologies for Independents (Area 2 – Exploration) Program of the U.S. Department of Energy, National Petroleum Technology Office, Tulsa, Oklahoma, contract number DE-FC26-03NT15424. The Contracting Officer's Representative is Virginia Weyland. Support was also provided by the Utah Geological Survey and Eby Petrography & Consulting, Inc., Littleton, Colorado.

Core and petrophysical data were provided by Tom Brown, Inc. (now Encana Corp.). James Parker of the Utah Geological Survey (UGS) drafted figures and Cheryl Gustin, UGS, formatted the manuscript. This report was reviewed by David Tabet and Michael Hylland of the UGS.

REFERENCES

- Ahr, W.M., 1989, Mississippian reef facies in the Southwest—a spectrum of variations in depositional style and reservoir characteristics: Ft. Worth Geological Society and Texas Christian University, Symposium on the Petroleum Geology of Mississippian Carbonates in North-Central Texas, p. 1-19.
- Baars, D.L., 1966, Pre-Pennsylvanian paleotectonics—key to basin evolution and petroleum occurrences in the Paradox Basin, Utah and Colorado: American Association of Petroleum Geologists Bulletin, v. 50, no. 10, p. 2082-2111.
- Chidsey, T.C., Jr., Eby, D.E., and Humphrey, J.D., 2005a, The Mississippian Leadville Limestone exploration play, Utah and Colorado: exploration techniques and studies for independents – semi-annual technical progress report for the period April 1, 2005 to September 30, 2005: U.S. Department of Energy, DOE/BC15424-4, 34 p.
- Chidsey, T.C., Jr., Eby, D.E., Morgan, C.D., McClure, K., Moore, J.N., and Humphrey, J.D., 2005b, Dolomitization of the Mississippian Leadville Limestone, Paradox Basin, southeastern Utah [abs.]: Abstracts with Programs, Geological Society of America, v. 37, no. 7, paper 4-12.
- Chidsey, T.C., Jr., Morgan, C.D., Eby, D.E., Moore, J., and Taylor, L. 2005c, The Mississippian Leadville Limestone exploration play, Utah and Colorado: exploration techniques and studies for independents – semi-annual technical progress report for the period October 1, 2004 to March 31, 2005: U.S. Department of Energy, DOE/BC15424-3, 69 p.
- Clark, C.R., 1978, Lisbon, San Juan County, Utah, *in* Fassett, J.E., editor, Oil and gas fields of the Four Corners area: Four Corners Geological Society, v. II, p. 662-665.
- Doelling, H.H., 2000, Geology of Arches National Park, Grand County, Utah, *in* Sprinkel, D.A., Chidsey, T.C., Jr., and Anderson, P.B., editors, Geology of Utah's parks and monuments: Utah Geological Association Publication 28, p. 11-36.

- Eby, D.E., Chidsey, T.C., Jr., Morgan, C.D., McClure, K., Humphrey, J.D., Moore, J.N., Taylor, L.H., and Weyland, V.H., 2005, Dolomitization of the Mississippian Leadville reservoir at Lisbon field, Utah [abs.]: American Association of Petroleum Geologists Annual Convention, Official Program with Abstracts, v. 14, p. A40.
- Fouret, K.L., 1982, Depositional and diagenetic environments of the Mississippian Leadville Formation at Lisbon field, Utah: College Station, Texas A&M University, M.S. thesis, 119 p.
- 1996, Depositional and diagenetic environments of the Mississippian Leadville Limestone at Lisbon field, Utah, *in* Huffman, A.C., Jr., Lund, W.R., and Godwin, L.H., editors, Geology and resources of the Paradox Basin: Utah Geological Association Publication 25, p. 129-138.
- Harry, D.L., and Mickus, K.L., 1998, Gravity constraints on lithospheric flexure and the structure of the late Paleozoic Ouachita orogen in Arkansas and Oklahoma, south-central North America: *Tectonics*, v. 17, no. 2, p. 187-202.
- Hintze, L.F., 1993, Geologic history of Utah: Brigham Young University Geology Studies Special Publication 7, 202 p.
- Johnson, C.F., 1970, Top of structure of the Leadville Limestone, Lisbon field: unpublished map, Union Oil Company of California files.
- Kluth, C.F., 1986, Plate tectonics of the Ancestral Rocky Mountains, *in* Peterson, J.A., editor, Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir 41, p. 353-369.
- Kluth, C.F., and Coney, P.J., 1981, Plate tectonics of the Ancestral Rocky Mountains: *Geology*, v. 9, p. 10-15.
- Morgan, C.D., 1993, Mississippian Leadville Limestone, *in* Hjellming, C.A., editor, Atlas of major Rocky Mountain gas reservoirs: New Mexico Bureau of Mines and Mineral Resources, p. 94.
- Parker, J.M., 1981, Lisbon field area, San Juan County, Utah, *in* Wiegand, D.L., editor, Geology of the Paradox Basin: Rocky Mountain Association of Geologists Guidebook, p. 89-100.
- Parker, J.W., and Roberts, J.W., 1963, Devonian and Mississippian stratigraphy of the central part of the Colorado Plateau: Four Corners Geological Society, 4th Field Conference Guidebook, p. 31-60.
- Petroleum Information, 1984, Paradox Basin—unravelling the mystery: *Petroleum Frontiers*, v. 1, no. 4, p. 22.

- Smith, K.T., and Prather, O.E., 1981, Lisbon field – lessons in exploration, *in* Wiegand, D.L., editor, *Geology of the Paradox Basin*: Rocky Mountain Association of Geologists Guidebook, p. 55-59.
- Smouse, DeForrest, 1993, Lisbon, *in* Hill, B.G., and Bereskin, S.R., editors, *Oil and gas fields of Utah*: Utah Geological Association Publication 22, non-paginated.
- Stevenson, G.M., and Baars, D.L., 1987, The Paradox—a pull-apart basin of Pennsylvanian age, *in* Campbell, J.A., editor, *Geology of Cataract Canyon and vicinity*: Four Corners Geological Society, 10th Field Conference, p. 31-55.
- Utah Division of Oil, Gas and Mining, 2007, Oil and gas production report, February: Online, <http://www.ogm.utah.gov/oilgas/PUBLICATIONS/Reports/PROD_book_list.htm>, accessed July 18, 2007.
- Welsh, J.E., and Bissell, H.J., 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Utah: U.S. Geological Survey Professional Paper 1110-Y, 35 p.
- Wilson, J.L., 1975, *Carbonate facies in geologic history*: New York, Springer-Verlag, 471 p.

APPENDIX

FIELD MAPS, LISBON FIELD, SAN JUAN COUNTY, UTAH

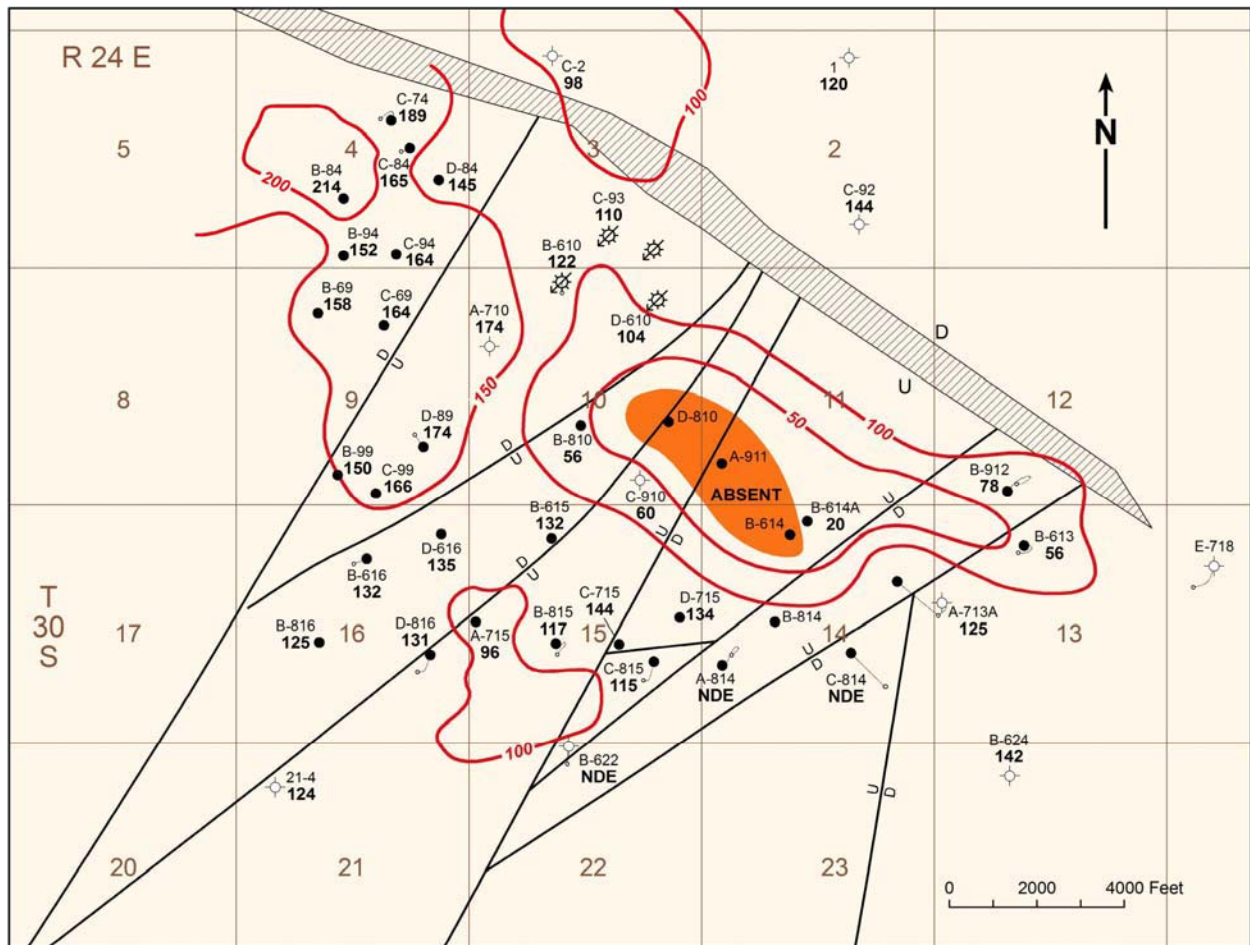


Figure A-1

Isochore Zone 1
(Contour interval 50 feet)
Leadville Limestone

Lisbon Field
San Juan County, Utah

EXPLANATION

- Oil well
- ◊ Dry hole
- ⊗ Gas injection well
- Minor fault
- ▨ Major fault
- Well name
- C-815 115 Interval thickness (ft)
- Surface location
- Bottom-hole location
- NDE = Not deep enough

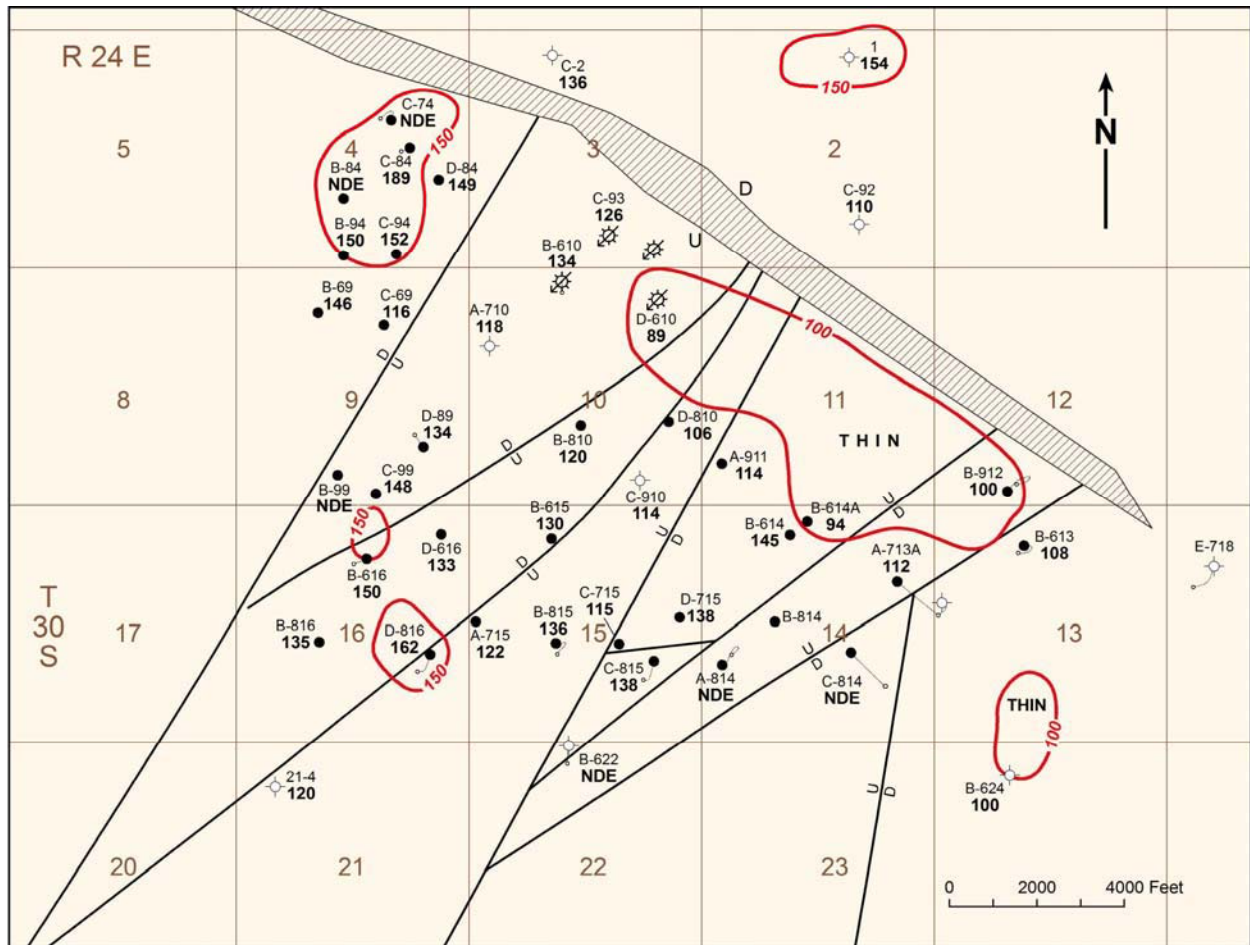


Figure A-2

Isochore Zone 2
(Contour interval 50 feet)
Leadville Limestone

Lisbon Field
San Juan County, Utah

EXPLANATION

- Oil well
- ◇ Dry hole
- ⊗ Gas injection well
- Minor fault
- ▨ Major fault
- Well name
- Interval thickness (ft)
- Surface location
- Bottom-hole location
- NDE = Not deep enough

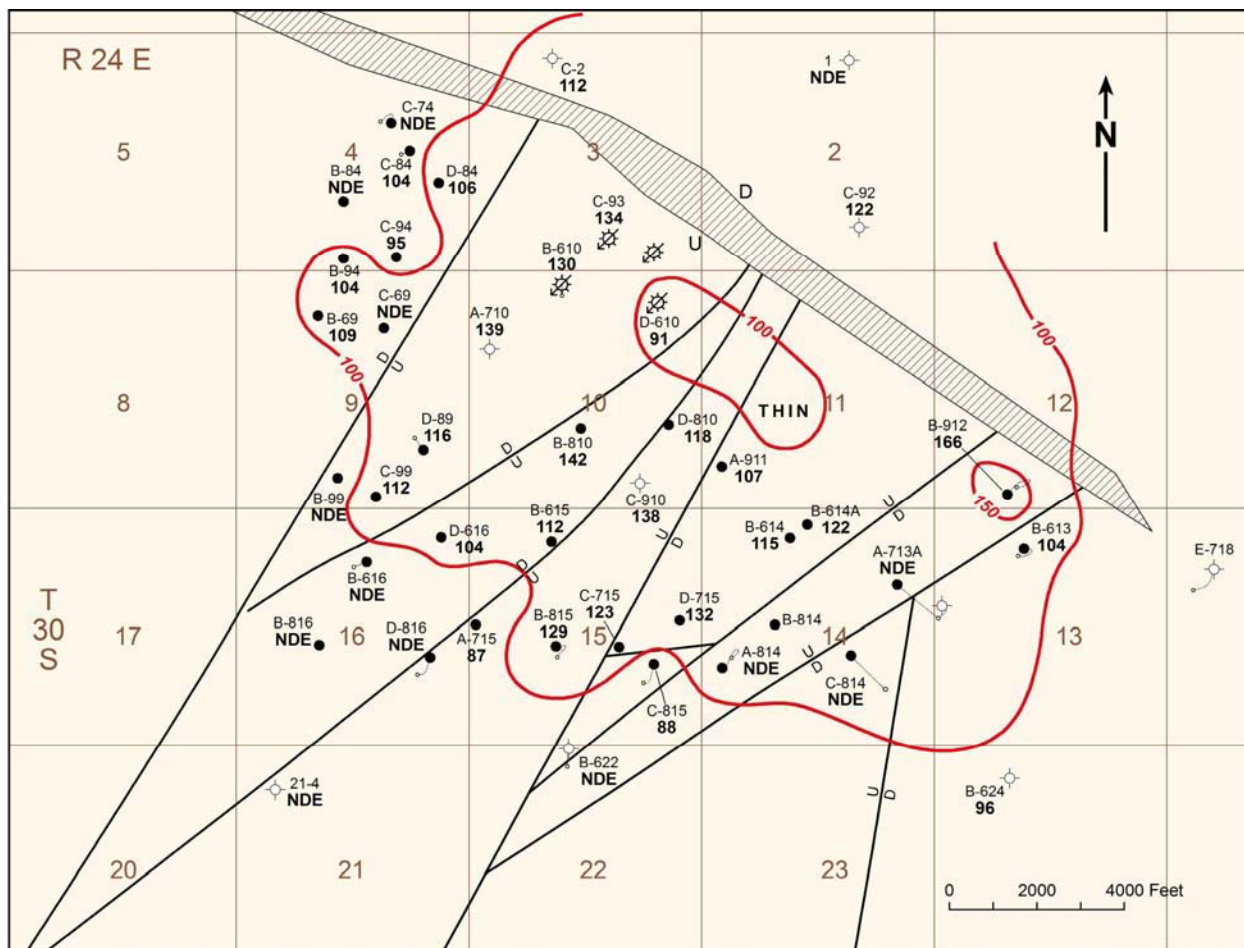


Figure A-3

Isochore Zone 3
(Contour interval 50 feet)
Leadville Limestone

Lisbon Field
San Juan County, Utah

EXPLANATION

- Oil well
- ⊙ Dry hole
- ⊗ Gas injection well
- Minor fault
- ▨ Major fault
- Well name
- Interval thickness (ft)
- Surface location
- Bottom-hole location
- NDE = Not deep enough

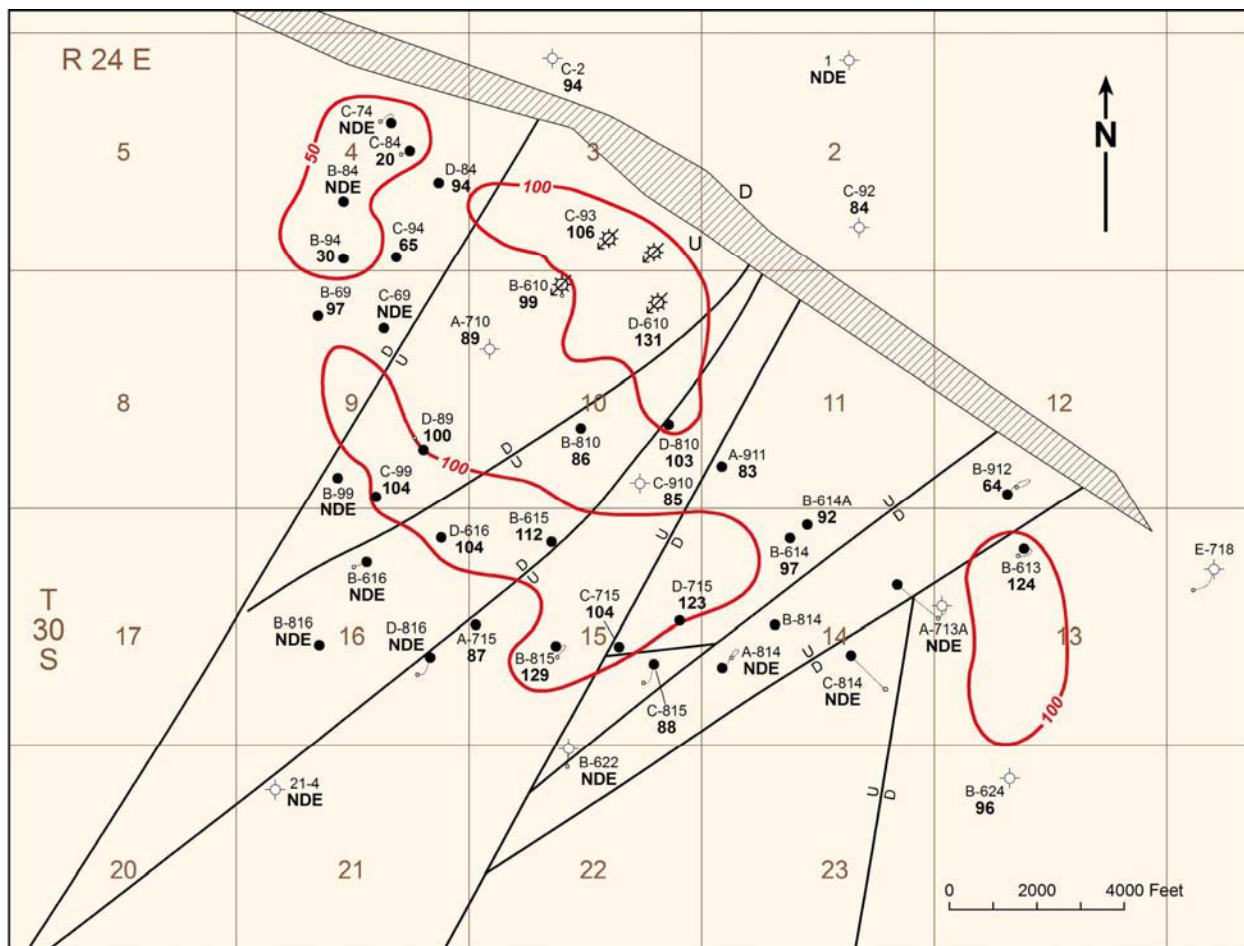


Figure A-4

Isochore Zone 4
(Contour interval 50 feet)
Leadville Limestone

Lisbon Field
San Juan County, Utah

EXPLANATION

- Oil well
- Dry hole
- ⊗ Gas injection well
- Minor fault
- ▨ Major fault
- Well name
- Interval thickness (ft)
- Surface location
- Bottom-hole location
- NDE = Not deep enough

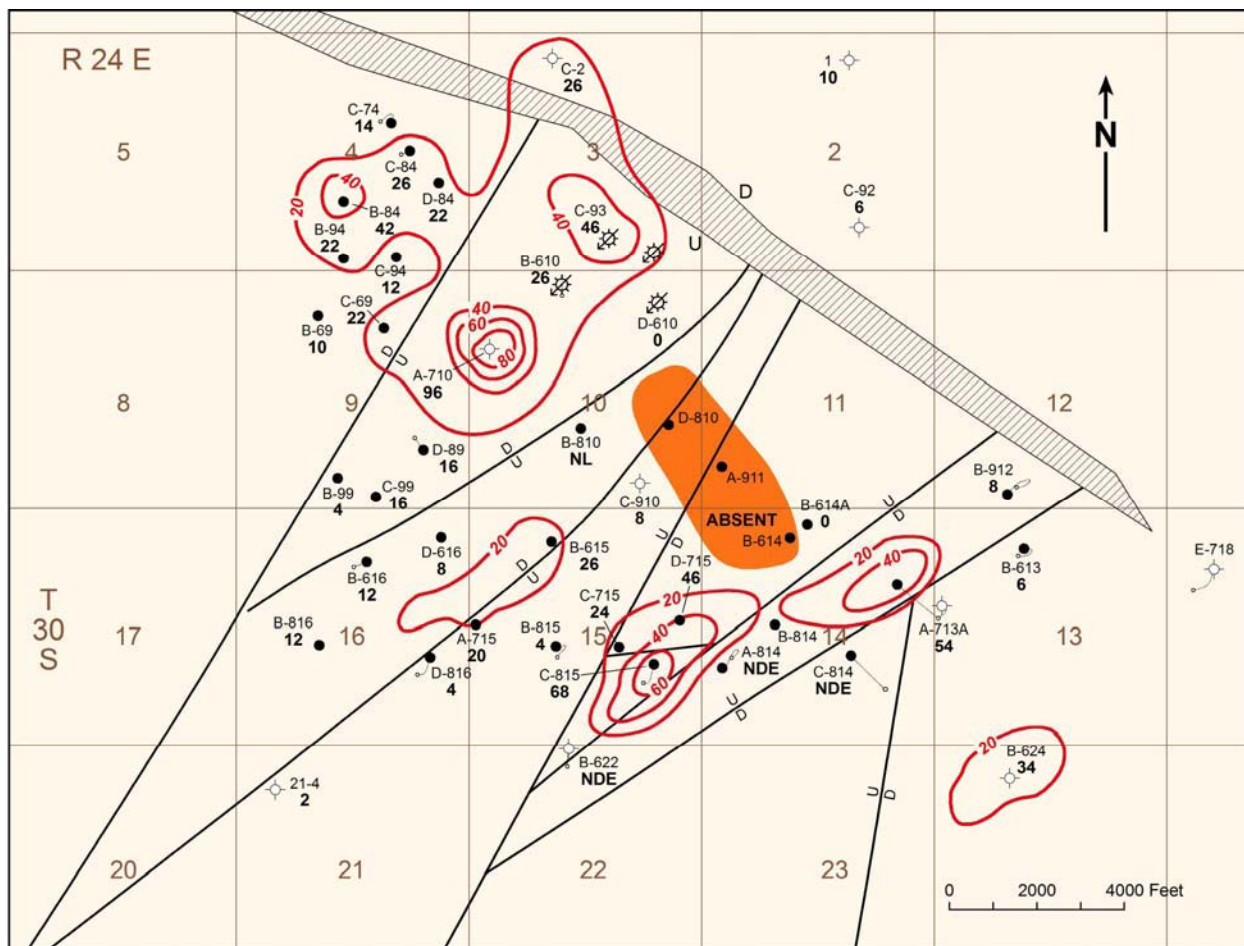


Figure A-5

Zone 1 - Feet of Porosity >10%

(Contour interval 20 feet)

Leadville Limestone

Lisbon Field

San Juan County, Utah

EXPLANATION

- Oil well
- ⊙ Dry hole
- ⊗ Gas injection well
- Minor fault
- ▨ Major fault
- Well name
- Interval thickness (ft)
- Surface location
- Bottom-hole location
- NDE = Not deep enough

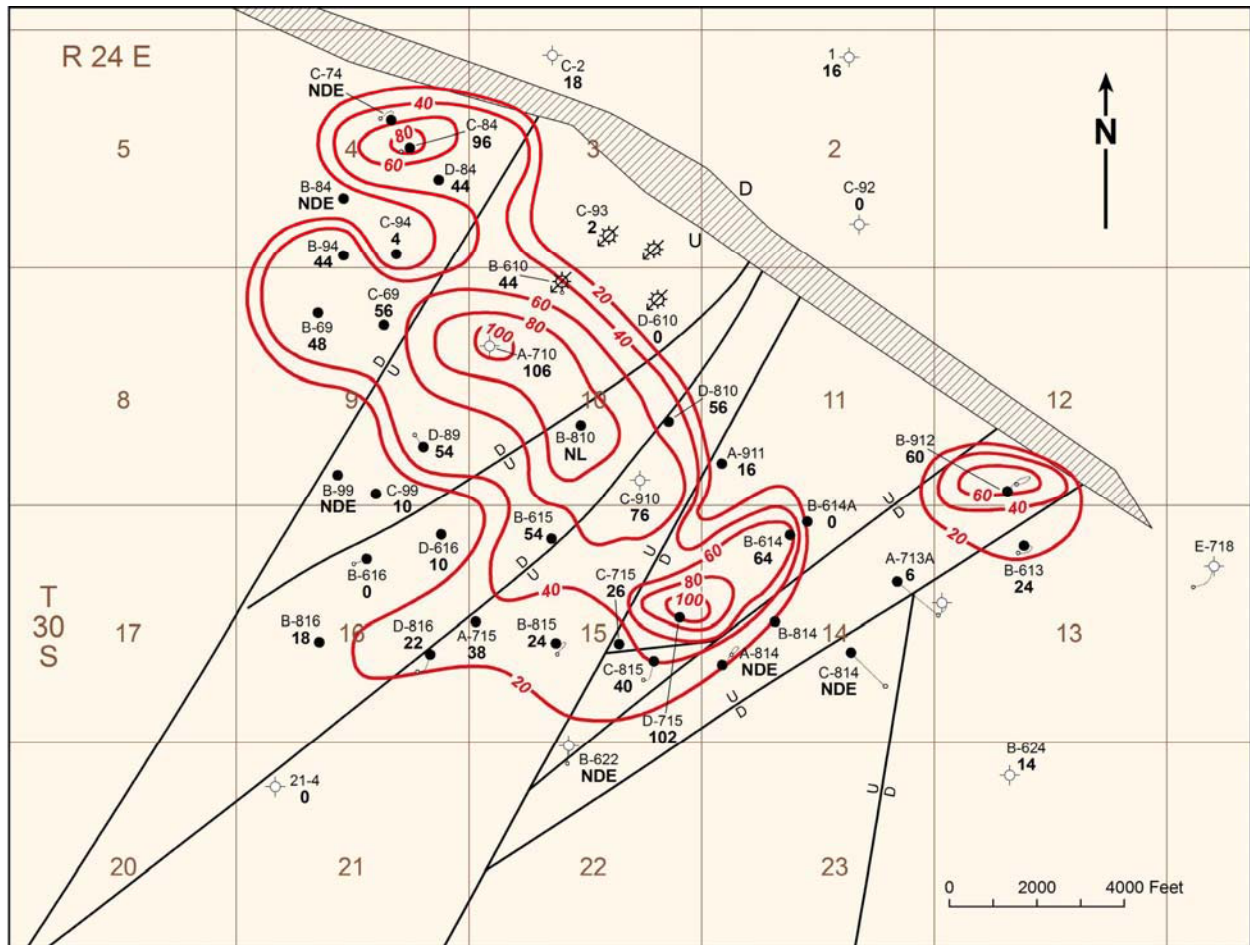


Figure A-6

Zone 2 - Feet of Porosity >10%
(Contour interval 20 feet)
Leadville Limestone

Lisbon Field
San Juan County, Utah

EXPLANATION

- Oil well
- Dry hole
- ⊗ Gas injection well
- Minor fault
- ▨ Major fault
- Well name
- Interval thickness (ft)
- Surface location
- Bottom-hole location
- NDE = Not deep enough

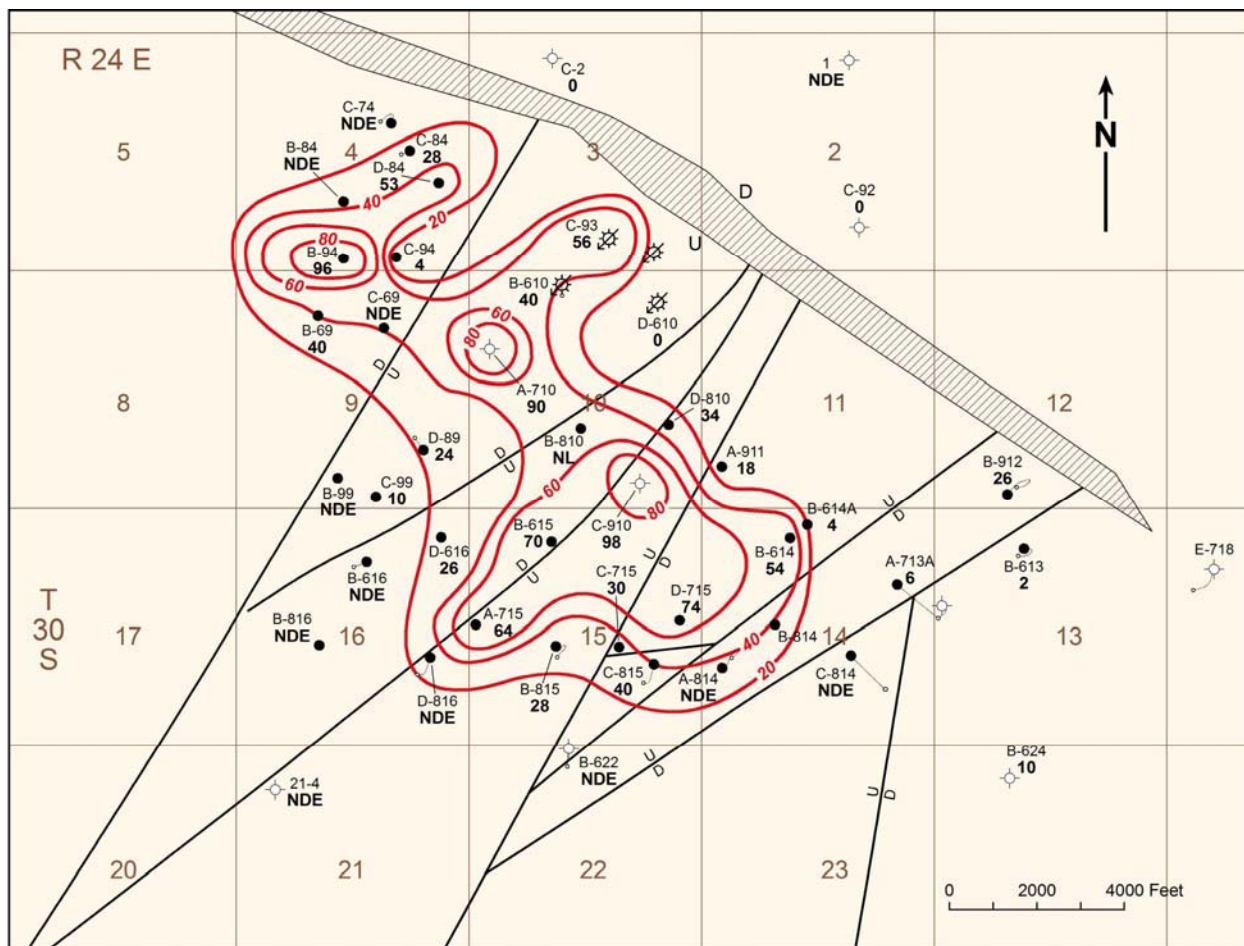


Figure A-7

Zone 3 - Feet of Porosity >10%
(Contour interval 20 feet)
Leadville Limestone

Lisbon Field
San Juan County, Utah

EXPLANATION

- Oil well
- ⊙ Dry hole
- ⊗ Gas injection well
- Minor fault
- ▨ Major fault
- Well name
- C-815 40 Interval thickness (ft)
- Surface location
- Bottom-hole location
- NDE = Not deep enough

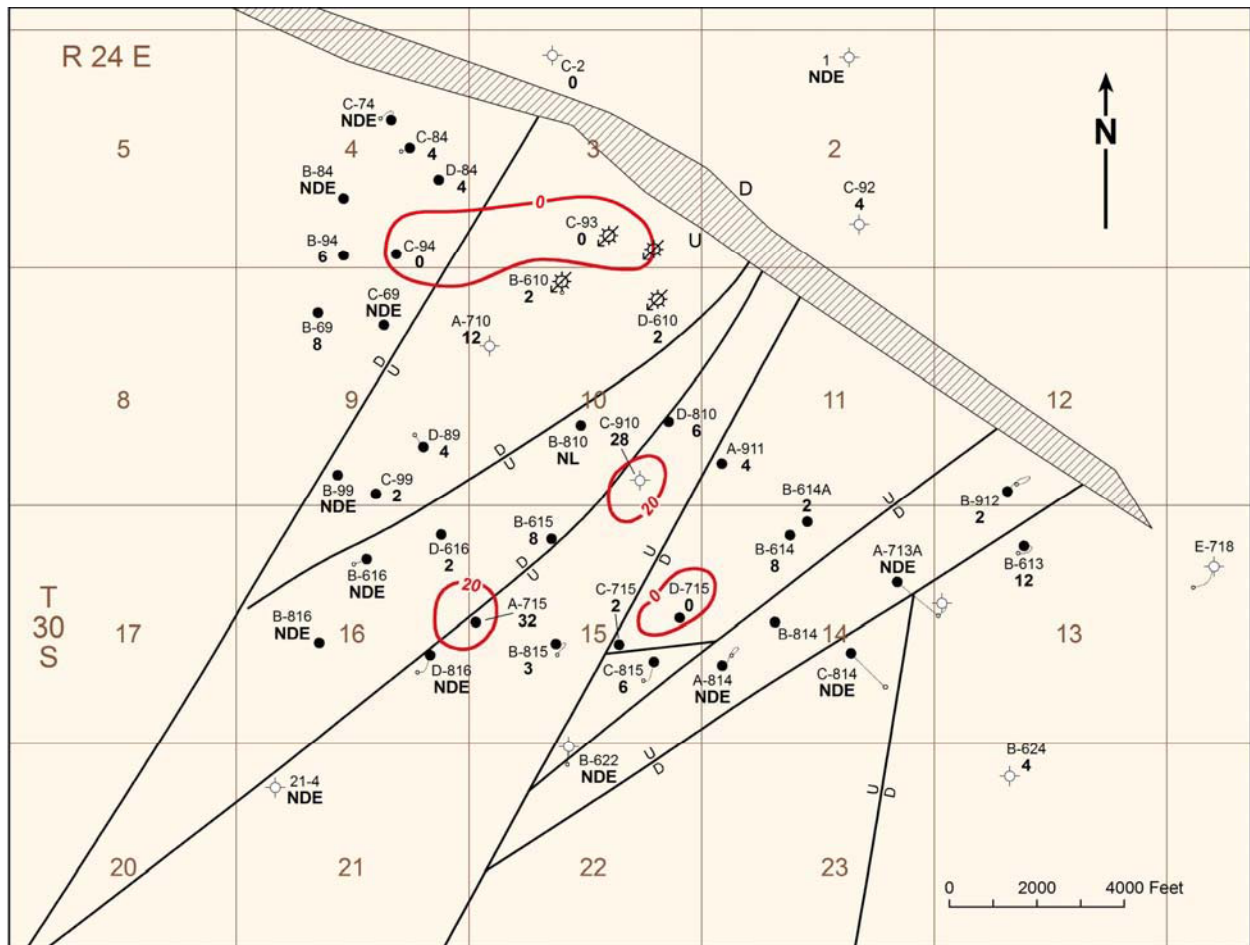


Figure A-8

Zone 4 - Feet of Porosity >10%
(Contour interval 20 feet)
Leadville Limestone

Lisbon Field
San Juan County, Utah

EXPLANATION

- Oil well
- Dry hole
- ⊠ Gas injection well
- Minor fault
- ▨ Major fault
- Well name
- Interval thickness (ft)
- Surface location
- Bottom-hole location
- NDE = Not deep enough

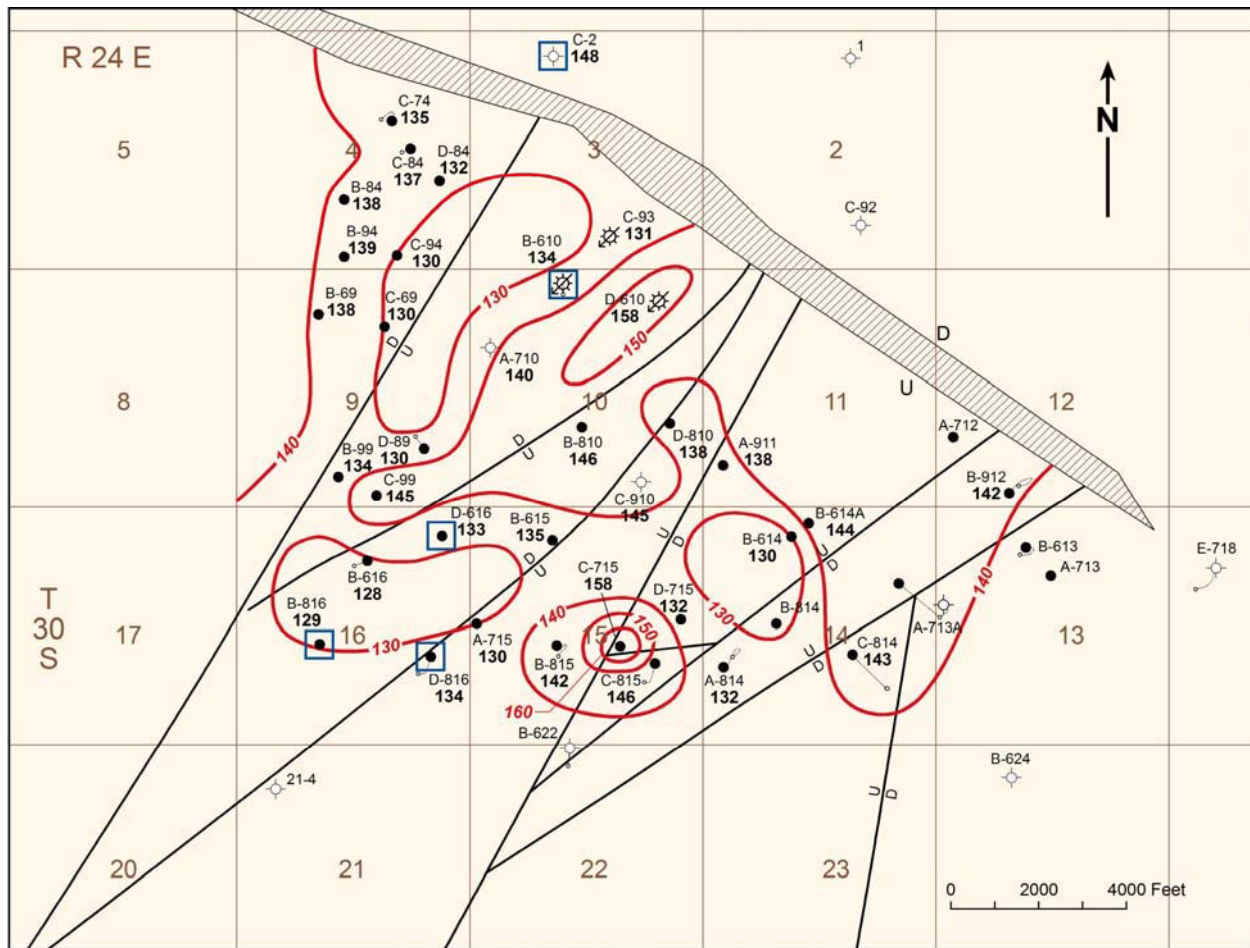


Figure A-9

Bottom-Hole Temperature
(Contour interval 10 degrees Fahrenheit)
Leadville Limestone

Lisbon Field
San Juan County, Utah

EXPLANATION

- Oil well
- ⊙ Dry hole
- ⊗ Gas injection well
- Minor fault
- ▨ Major fault
- Project core
- Well name
- Interval thickness (ft)
- Surface location
- Bottom-hole location
- NDE = Not deep enough

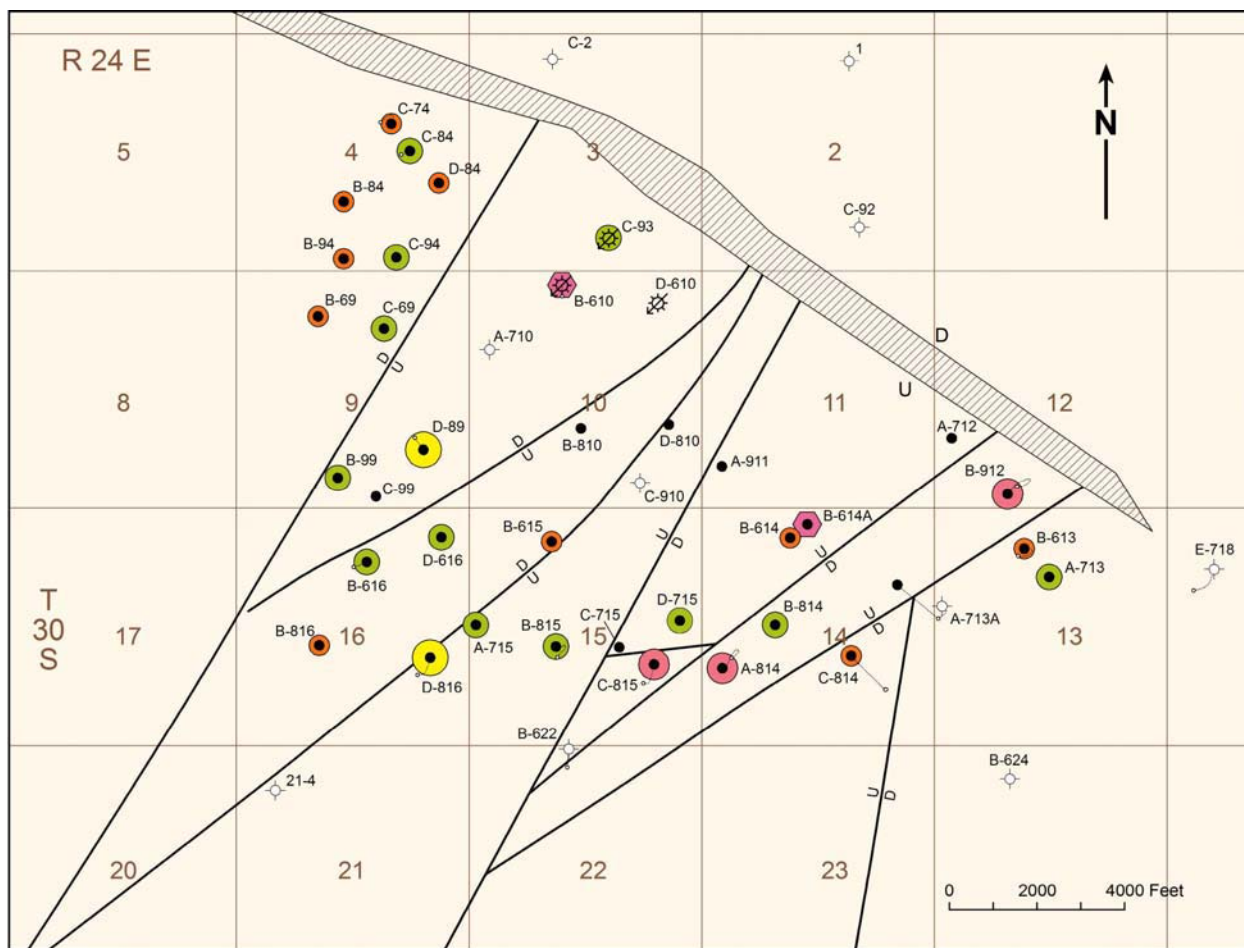


Figure A-10

Initial Flowing Potential Leadville Limestone

Lisbon Field
San Juan County, Utah

EXPLANATION

- Oil well
- Dry hole
- ⊠ Gas injection well
- Minor fault
- ▬ Major fault
- Well name
- Surface location
- Bottom-hole location
- NDE = Not deep enough
- 100 to 500 BOPD
- 500 to 1000 BOPD
- 1000 to 1500 BOPD
- >1500 BOPD
- 2-4.4 MMCFGPD

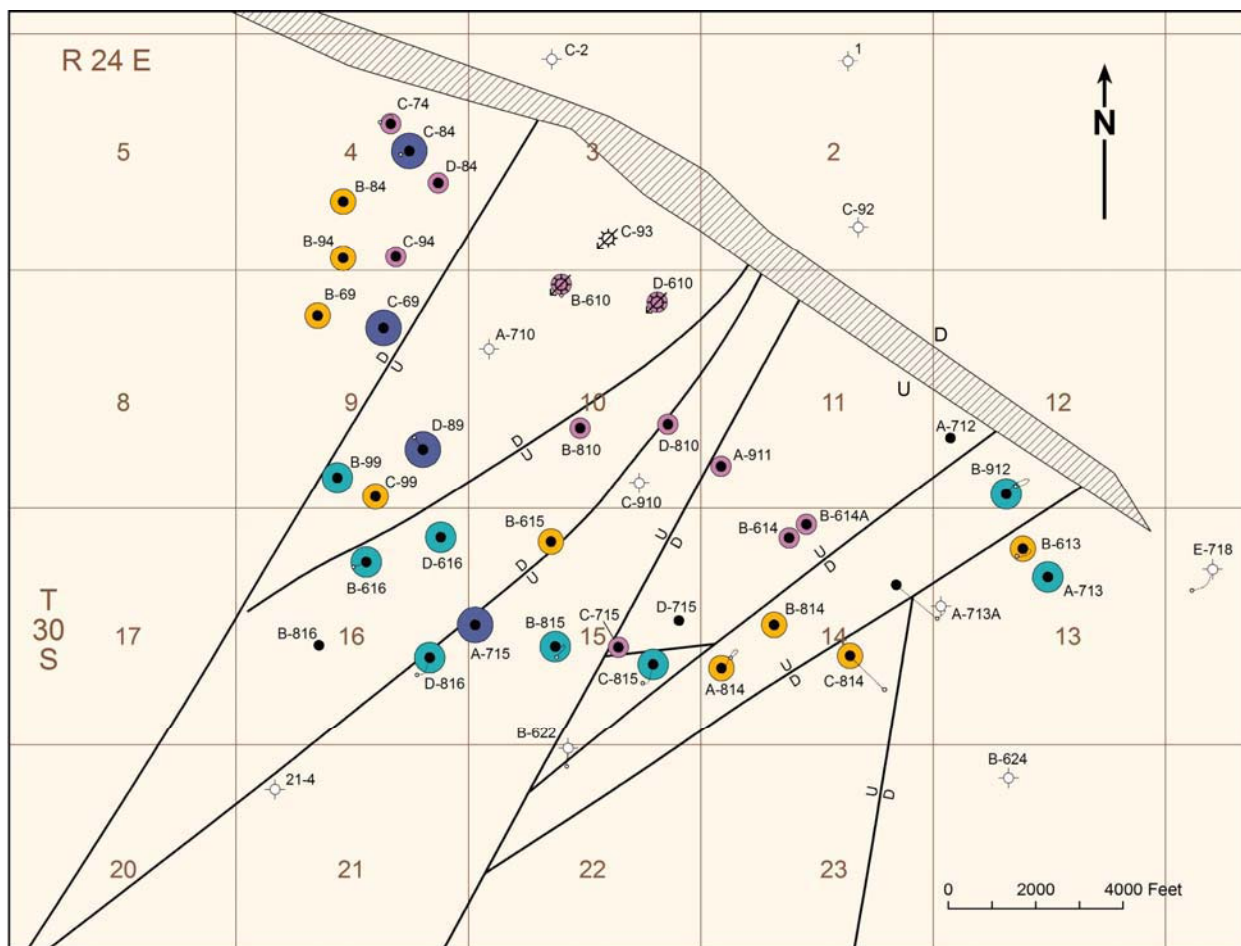


Figure A-11

Cumulative Oil Production Leadville Limestone

Lisbon Field
San Juan County, Utah

EXPLANATION

- Oil well
- Dry hole
- ⊗ Gas injection well
- $\frac{D}{U}$ Minor fault
- Major fault
- Well name
- Surface location
- Bottom-hole location
- NDE = Not deep enough
- <100 MBO
- 100 to 1000 MBO
- 1000 to 5000 MBO
- >5000 MBO

National Energy Technology Laboratory

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880

One West Third Street, Suite 1400
Tulsa, OK 74103-3519

1450 Queen Avenue SW
Albany, OR 97321-2198

2175 University Ave. South
Suite 201
Fairbanks, AK 99709

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A
SOUTH

● Pure Oil Company
NW Lisbon USA C-81's (E-1)
NW1/4SE1/4 section 15,
T.30 S., R.24 E., SLBLM
KB 6181 feet
API:43-037-16249

● Pure Oil Company
NW Lisbon USA D-810 (A-2)
NE1/4SE1/4 section 10,
T.30 S., R.24 E., SLBLM
KB 6640 feet
API:43-037-16471

● Tie with line B-B'
Pure Oil Company
NW Lisbon B-610 (A-1)
SW1/4NW1/4 section 10,
T.30 S., R.24 E., SLBLM

● Pure Oil Company
NW Lisbon B-610 (C-3)
SW1/4NE1/4 section 3,
T.30 S., R.24 E., SLBLM
KB 6798 feet
API:43-037-16470

● Pure Oil Company
NW Lisbon USA B-63 (C-2)
NE1/4NW1/4 section 3,
T.30 S., R.24 E., SLBLM
KB 6803 feet
API:43-037-11339

● Pure Oil Company
USA Big Indian 1
SE1/4NE1/4 section 33
T.29 S., R.24 E., SLBLM
KB 7124 feet
API:43-037-16219

A'

NORTH

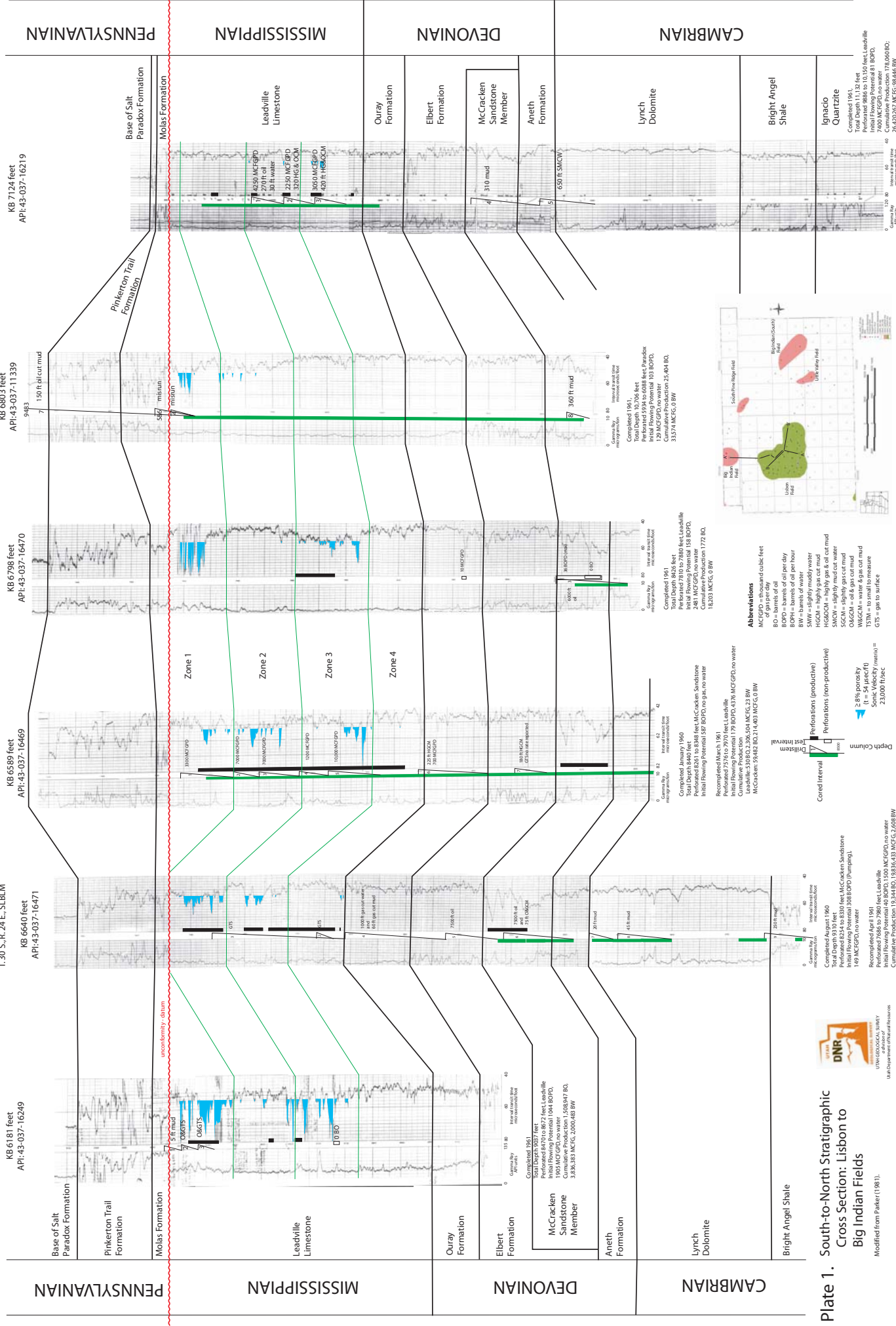


Plate 1. South-to-North Stratigraphic Cross Section: Lisbon to Big Indian Fields

Modified from Parker (1981).

B
WEST

B'
EAST

